Some Limitations of Quantitative Risk Analysis Approaches Used in Project Management

From the Forthcoming Book: "Project Risk Management: Keys to Successful Implementation"
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1.0 Introduction

I briefly explore in this paper some of the inherent limitations of quantitative risk analysis as applied to project management. Specific areas addressed include the computation of risk and use of ordinal scales, and some limitations associated with performing Monte Carlo simulations.

This material is not presented to negate or criticize the results that will be obtained in a typical risk analysis, but to point out problems that often exist, are often unknown to both analysts and decision makers, and can limit the usefulness of results. Simply stated, blindly accepting quantitative risk analysis results is unwise and can lead to a variety of potential problems. Decision makers are urged to exercise considerable caution in basing major program decisions primarily on such data without carefully analyzing what it represents and what its limitations are. (There is, unfortunately, very little objective information on the limitations of quantitative risk analysis in the literature. Providing decision makers with such information is the primary purpose of pre-publishing this material.)

I have observed the problems discussed below for a number of years on actual programs. These programs typically have a life cycle cost exceeding $1 Billion (Then Year). The sample of programs: (1) spans Air Force, Army, Department of Defense, Navy and classified customers; (2) includes the largest contractors in the defense industry; and (3) includes space, air, ground and sea operating environments. Consequently, it is safe to say that these problems are commonplace and may approach universal existence in large defense programs. And unfortunately, they are also commonplace in large-scale commercial programs and can be routinely found in a body of widely distributed project management literature.

I will now briefly explore some inherent limitations of typical risk analysis methodologies and results. (Solutions are provided to some of the problems below. Additional information will be provided in my forthcoming book (1999).)

2.0 Computation of Risk and the Use of Ordinal Scales

The computation of risk strictly requires the use of probability data. Given this requirement, risk or a "risk factor" **cannot** be computed from ordinal scales (whose definitions correspond to rank ordered scale values), since ordinal scale results can never yield probabilities unless the scales themselves were originally created from probability data (which is almost never the case). A probability value must either come from "real world" measurements, a validated simulation, or other cogent sources. Consequently, it is appropriate when using ordinal scales to flag the probability term as "probability".

In addition, a probability cannot be created or assigned by an analyst without basis or merit as often is the case in performing risk analyses. If you create probability values out of "thin air"--the results are generally uncertain if no meaningless, and basing program decisions on such results can be dangerous. For example, if a five level ordinal scale exists, it is invalid to assume that the probability values associated with these five levels are $0 \leq$ Level $1 \leq 0.2$, $0.2 <$ Level $2 \leq 0.4$, $0.4 <$ Level $3 \leq 0.6$, $0.6 <$ Level $4 \leq 0.8$, and $0.8 <$ Level $5 \leq 1.0$. It is similarly invalid to make subjective guesses of the probability as being one of 5 levels (very low, low, medium, medium high and high) then attempt to equate these levels with $0 \leq$ Level $1 \leq 0.2$, $0.2 <$ Level $2 \leq 0.4$, $0.4 <$ Level $3 \leq 0.6$, $0.6 <$ Level $4 \leq 0.8$, and $0.8 <$ Level $5 \leq 1.0$. These two types of subjective probability encoding errors are illustrative of a broad range of problems that commonly exist.
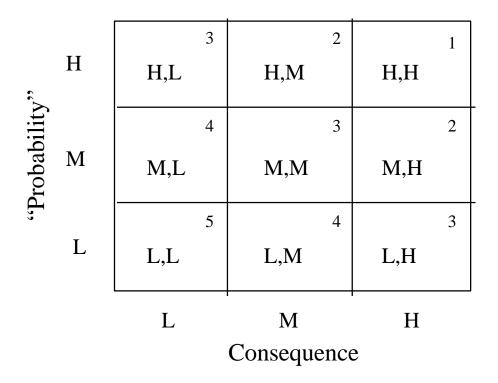
If ordinal scales are uncalibrated, meaning no attempt has been made to ascertain the true interval between adjacent scale levels, then performing mathematics on or between the "probability" and consequence scales almost always yields meaningless results. For example, you can't multiply the "probability" and consequence scale values, sum the results or compute an average. These results will be invalid--they will present a false aura of accuracy and confidence that does not really exist.

If the ordinal scales are calibrated (e.g., using the Analytical Hierarchy Process (AHP)), meaning a structured attempt has been made to ascertain the true interval between adjacent scale levels, the results still cannot yield risk since no probability values exist unless actual probability data was used to generate or calibrate the scales. While AHP or other calibration methods may provide a helpful relative calibration within a scale for different levels, or between different ordinal scales, it will not calibrate any given scale level or weighting between scales with actual values, but only relative values, unless actual values can be separately derived and provided [1].

As with any risk analysis technique, there is generally substantial uncertainty in the first decimal place, and succeeding decimal places are increasingly uncertain. Simply stated, basing a program decision on whether a risk analysis result is 0.70 or 0.65 is dangerous when either value typically has an unknown uncertainty range that might be +/- 0.2 or larger. A better approach is to assume that any item with a medium or high risk assigned from risk analysis should be carefully evaluated and suitable risk handling options explored.

In summary, risk can only be computed from probability of occurrence and consequence of occurrence terms. Since ordinal scale values are almost never derived from real probability data, risk **cannot** be computed from ordinal scales. A proxy of risk (but not risk itself) can be implied from the combination of the "probability" term and the consequence term derived from uncalibrated ordinal scales so long as no mathematical operations are performed. In effect, the "probability" and consequence terms are mapped by a pre-determined methodology into low, medium and high categories. (A different proxy of risk can be implied from the product of calibrated "probability" and consequence ordinal scales, which yields a "weighted product of relative importance" to the program. Here, a resulting score of 3.0 would be twice as important to the program as a score of 1.5 even though neither score is true risk (probability times consequence).)

One method of summarizing the results of a risk analysis using uncalibrated ordinal scales is the risk handling priority matrix given in Figure 1. This approach does not violate any principals or assumptions associated with risk, its requirement for having a true probability term (in the strictest sense), and the characteristics associated with ordinal scales that may be used to generate the "probability" and consequence scores. (Other, more sophisticated techniques for mapping ordinal scale scores into risk levels exist but are not discussed here.)

		L	M	H
"Probability"	**H**	3 H,L	2 H,M	1 H,H
	M	4 M,L	3 M,M	2 M,H
	L	5 L,L	4 L,M	3 L,H
		L	M	H

Consequence

Risk Handling Priority Matrix
Figure 1

Row and column matrix numbering is used as an illustration in Figure 1 to identify the level of "probability" and consequence present in each cell. It is important to note that the risk handling priority increases away from the (L,L) origin. In Figure 1 the data has been segregated into five risk handling priority classes. This can be reduced to three classes by collapsing (H,H; H,M; and M,H) into Class 1, (H,L; M,M; and L,H) into Class 2, and (M,L; L,M; and L,L) into Class 3.

Here, no assumption is made pertaining to the origin of the "probability" and consequence scores, only that the mapping into L,M,H levels has been correctly performed. (If the original ordinal scales have three levels, then these levels can be directly mapped into L,M,H. If the scales have more than three levels, then the original levels will have to be compressed into L,M,H.) For example, the representation given in Figure 1 is valid for results generated from calibrated or uncalibrated ordinal scales so long as the mapping into L,M,H cells is properly performed.

Finally, many schemes for summarizing risk issues at higher levels of integration (e.g., higher WBS levels) are fraught with problems. Typically, one of two problems occur, namely incorrect mathematical computation of risk values or diminishing risk values at higher WBS levels. Risk values derived from uncalibrated ordinal scales will yield meaningless results when aggregated at higher levels of integration. Such risk values should not be mathematically aggregated. If aggregation is necessary, the conservative approach is that the highest risk (both "probability" and consequence terms) that existed at the initial evaluation level should be elevated to higher WBS levels undiminished. (For example, a high "probability" of occurrence item at WBS level 7 (e.g., detector chip) should flow upward to make the resulting WBS level 4 (e.g., sensor) "probability" value high.) Values generated from calibrated ordinal scales will typically not be true "risk" (as previously discussed), but may yield meaningful results. A potential problem in using calibrated ordinal scale data in roll-ups follows. As the number of WBS roll-up levels increases, the impact that a given risk issue at a lower WBS level has on the resulting score diminishes. It is not uncommon that an item identified as high risk may have little numerical impact when rolled up three or four WBS levels. The solution to this problem is to "flag" any item with a medium or high risk and require a viable risk handling strategy be developed for it.

3.0 Some Limitations Associated with Performing Monte Carlo Simulations

A host of potential problems exist with many quantitative risk analysis methodologies. Perhaps the biggest problem is that there is no single correct methodology nor best methodology for performing quantitative risk analysis when actual probability data is absent. However, some methodologies are potentially better than others, and some methodologies contain serious flaws that will lead to highly erroneous, if not meaningless, results. A number of potential problems exist associated with using Monte Carlo simulations for quantitative risk analysis. (The Monte Carlo method is a technique for numerically approximating the solution of a mathematical problem by studying the distribution of some random variable, often generated by a computer

[2].) Several limitations of selecting the type and characteristics of probability distributions for use in Monte Carlo simulations are now briefly discussed.

First, there is no statistically sound basis to specify the commonly used triangle, beta or lognormal distribution for use in Monte Carlo simulations. (Historical use and convenience **are not** statistically sound reasons.) I am not aware of any studies published in the literature that derived distribution types by curve fitting actual program data below the total program level. (For example, a curve fit would be performed on 40 or more similar focal plane array data points to see if a triangle distribution was a good post priori indicator of risk (dollar cost growth) versus initial development estimates at the 0.05 statistical confidence level.) Curve fits that have been performed on post priori cost and schedule data at the total program level in fact indicate the lognormal and beta distributions **do not** accurately represent the underlying program information [3]. Similarly, data at the total program level show that there is **no basis** for selecting or specifying a joint cost-schedule risk distribution based upon a triangle, lognormal or beta distribution [3].

Second, there is no clear mathematical or probabilistic basis for multiplying a most likely cost or schedule times an estimate of technical risk to obtain the upper bound (high value) of a triangle distribution for a given Work Breakdown Structure (WBS) element as is commonly done. This is true even if the resulting multiplier has been derived from calibrated ordinal scales. If the multiplier is derived from uncalibrated ordinal scales, then the resulting value is almost always meaningless and an unrecognized noise source in the simulation. In general, the selection of critical values for a distribution (e.g., endpoints of a triangle distribution) is often at least moderately subjective with weak, if not erroneous, methodology employed and supporting rationale. While some structured approaches are better than others, analysts and decision makers should recognize that an unknown level of uncertainty is often present (as discussed below) that can substantially impact the results.

Third, there is no mathematical or probabilistic basis to create "custom tailored" probability distributions (e.g., a custom distribution of two joined triangles) when underlying "real world" data is absent, simply to change the nature of the results. At best this is a leap of faith, and at worst, this is gaming the objective of performing the simulation to generate skewed results (regardless of the motive).

Fourth, correlation between risk analysis elements sometimes exist, but accurately modeling it is often illusive. For example, WBS elements associated with required launch support for a spacecraft should be correlated with the level of government temporary duty needed. However, the magnitude of the correlation coefficient (-1 to +1) is typically guessed, with little or no historical evidence to validate the selected value. Although schemes have been developed that equate a subjective level of correlation to a resulting correlation coefficient magnitude (e.g., "high" correlation is 0.8 magnitude), I am not aware of any published evidence that these techniques are accurate. And using incorrect magnitudes of correlation between elements will introduce an error into the simulation results. Consequently, non-zero correlation magnitudes

should be estimated and used with considerable caution since the resulting "benefit" may be outweighed by an unknown error that is introduced.

Fifth, allocation of cumulative distribution function risk analysis results back to individual WBS elements is generally problematic since the uncertainty level present is likely in the first or second decimal place of the results. Hence, even if the allocation is "numerically correct", the results will be uncertain and at least somewhat erroneous. Thus, decision makers should use considerable caution in evaluating the allocation of risk dollars or time back to individual WBS elements or activities, respectively when such information may impact actual program decisions and not just be an academic exercise.

Sixth, an unknown uncertainty exists for almost every quantitative risk analysis. I am not aware of any studies published in the literature that thoroughly estimated the effect of uncertainty present in the input data (e.g., variations in the critical distribution values associated with the probability distributions included in all WBS elements simulated), type of probability distribution (e.g., triangle), level of correlation selected for WBS elements, and other considerations. Consequently, the resulting Monte Carlo simulation probability density function and cumulative distribution function computed over a program's WBS elements or activities boils down to "best" guesses with generally **unknown confidence**. Given this situation, it is essential that program decisions not be made based upon slight variations in results because of the lack of certainty associated with them. For example, is a risk value of 0.70 different than 0.65 or 0.60? In many cases, probably not. And often in other cases the answer is typically neither "yes" or "no", but **unknown**. As previously mentioned, a better approach is to assume that any item with a medium or high risk assigned from risk analysis should be carefully evaluated and suitable risk handling options explored.

References

[1] Edmund H. Conrow, "The Use of Ordinal Risk Scales in Defense Systems Engineering," "1995 Acquisition Research Symposium Proceedings," Defense Systems Management College, June 1995.

[2] ____, " Webster's Encyclopedic Unabridged Dictionary of the English Language," Gramercy Books, New York, 1996, pg. 1246.

[3] Edmund H. Conrow, "Some Inherent Limitations of Quantitative Cost Risk Assessment Methodologies," 29th Annual DoD Cost Analysis Symposium, 21-23 February 1996. (This paper was winner of the best contractor paper of the symposium award.)

Vita

Dr. Edmund H. Conrow is an independent management and technical consultant located in Redondo Beach, California. He has 25+ years experience in the application of project management and technical skills to moderate to high complexity programs. This includes over 20 years experience in the development and analysis of cost, performance and schedule risk analyses, and in performing Monte Carlo simulations. He has successfully served a broad range of clients, including: industry, federally funded research centers, national laboratories and government. His work has been recognized in several disciplines with letters of commendation from several government departments and agencies and awards at national conferences, including: management strategy, CAIV, cost analysis, engineering design analysis, manufacturing, risk management and systems engineering. He holds a BS and MS in nuclear engineering (University of Arizona), Ph.D. in general engineering (Oklahoma State University) and Ph.D. in public policy analysis (RAND Graduate School). Dr. Conrow is highly published in national journals and conferences in risk management, CAIV, engineering design analysis, and management strategy. He is a Certified Management Consultant (Institute of Management Consultants), and a Project Management Professional (Project Management Institute). Dr. Conrow is the author of the forthcoming book, "Project Risk Management: Keys to Successful Implementation" (1999).

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